Architect Meet Ecologist: A Studio-Based Study of Massive Timber for an Ecological Research Lab

Dustin Albright[1]

[1]Clemson University, Clemson, South Carolina

ABSTRACT: This paper describes ongoing design research at Clemson University that explores the intersection between massive timber building systems, as leveraged for an academic facility, and topics of sustainable forestry, forest health, and carbon footprint. At the center is a topical design studio course in which students designed a new laboratory for Clemson's Baruch Institute for Coastal Ecologies and Forest Science (BICEFS), in Georgetown, South Carolina. Students were challenged to utilize massive timber building systems, including Cross-Laminated Timber (CLT), while discovering their structural and environmental benefits, and considering the potential impacts of the associated construction on the sensitive site. Additionally, students were required to examine the embodied energies of these timber systems using BIM and available estimation tools. This aspect was of particular interest to BICEFS, as it dovetails with their own research on carbon sequestration. The paper presents selections from the laboratory proposals as well as the carbon footprint data and related methodologies, all while considering the degree to which such questions can be successfully integrated into the design studio. The paper concludes by outlining research objectives for future phases of the project, including more in-depth LCA studies plus embedded monitoring of structural and envelope performance.

KEYWORDS: massive timber, carbon footprint, forest ecologies

INTRODUCTION

In the Fall of 2017, three studio design courses at Clemson University were combined to tackle a challenging service learning project for the Baruch Institute for Coastal Ecologies and Forest Science (BICEFS). In advance of its 50th anniversary, and while facing new infrastructure needs for its future, BICEFS turned to Clemson's School of Architecture for concepts for a new research laboratory, new researcher housing, and site design that tied its small campus together while establishing a framework for smart and environmentally sensitive growth. One critical layer to the project was the integration of timber building systems aimed at minimizing embodied energy and supporting the state's forest products industry. This paper focuses on the laboratory project, the utilization of "massive timber", and the dovetailing of timber construction with BICEFS' own forest research.

1.0 BACKGROUND AND SETTING

1.1. Massive Timber and its Place in South Carolina

In February of 2013, a collection of curious designers, builders, and wood products professionals gathered in Seattle for the U.S. Cross-Laminated Timber[1] (CLT) Symposium and the introduction of the U.S. CLT Handbook, a design guide addressing performance and construction topics associated with these timber panels (Douglas, 2013). Since that time, massive timber construction, using systems like CLT, has slowly begun to take hold in North America. What began with a few noteworthy projects in Canada and the Pacific Northwest has spread with projects in other regions. Moreover, industry R&D efforts contributed to the recognition of CLT in the 2015 International Building Code, and more expansive considerations are currently underway for future editions. However, one constraint on the wider implementation of these technologies has been a stalemate between production and perceived demand. Would-be producers in the U.S. have been slow to invest without solid knowledge of what the market will be, while owners and designers have been reluctant to pursue mass timber solutions without reliable production in their region. Still, a few domestic producers have recently emerged, and new projects are beginning in areas served by these factories. Other enterprising partnerships are positioning themselves to fuel both the demand and supply sides of the equation as developer/designer/fabricator.

Playing a crucial role in the interim period has been a key third player – academic institutions as clients. Schools such as the University of British Columbia, UMass, Georgia Tech, and the University of Arkansas have selected massive timber for new campus projects, thereby providing important case studies for the forest products and building industries. This has been spurred, in part, by vested faculty research interests in the areas of mass timber constructability, structural behavior, thermal performance, and economic and environmental impacts.[2] The marriage of detailed material research, full-scale implementation, and post-construction analysis has contributed to real advancements in the acceptance of these emerging technologies, as well as dynamic and productive interactions across all facets of industry, from designers to manufacturers to code officials and legislators. Drawing from these examples, and motivated to provide a model structure in South Carolina, Clemson University is currently planning a new outdoor recreation center that features CLT construction. As with other institutions, the decision to pursue mass timber was influenced by faculty research interests. In fact, this is the result of four years of discussion between the planning department and Clemson's cross-disciplinary Wood Utilization + Design (WU+D) Institute.

Moreover, the decision to pursue mass timber solutions at Clemson is grounded in their potential to positively impact the state's vital forest economy, and advance its sustainable forestry practices. According to a 2016 USDA report, South Carolina is home to 5.22 million hectares (12.9 million acres) of forested land, representing 63% of its gross area (Forests of SC, 2016). The forest industry contributes over $21 billion annually to the state's economy and represents the most significant manufacturing sector in terms of both jobs and labor income (Economic Contribution, 2017). Within this total, the solid wood products sector (including lumber, plywood, poles, trusses, millwork, etc.) contributes a direct economic output of $2.5 billion. On the supply side, the timber sector accounted for nearly $300 million of direct contribution, while the logging sector, which feeds the mills, accounted for $375 million (Economic Contribution, 2017). These supply numbers, while significant, are still lower than pre-recession numbers from 2006, but they have much room to grow if spurred by new or expanded timber markets. New markets might also prevent the conversion of timberlands to other non-forest uses, such as agriculture or development.

Of the state's forest area, 88% is privately owned, and the overall percentages of hardwoods versus softwoods are 52% to 48%, respectively. Loblolly-shortleaf pine, makes up the predominant species classification, accounting for 44% of all forests, while another Southern Pine variety, longleaf pine, makes up the remaining 4% of softwoods (Forests of SC, 2016). Southern Pine dominates the wood products market throughout the Southeast, and its share stands to increase further if mass timber systems gain a foothold. Southern Pine CLT has been the subject of much research and testing within Clemson's WU+D Institute, and the region's first CLT manufacturer will utilize Southern Pine when it begins operations in late 2018.[3] Considering the potential economic impacts, plus the intersecting research interests of BICEFS and the WU+D Institute, as well as the practical momentum represented by Clemson's planned mass timber recreation center, the studio faculty and the BICEFS director agreed to emphasize mass timber structural systems for the proposed new laboratory.

1.2. BICEFS and its Needs

The Baruch Institute for Coastal Ecologies and Forest Science (BICEFS), located in Georgetown, South Carolina, is one of eight research stations operated by Clemson University's Public Service and Agriculture (PSA) program. BICEFS operates from the historic Hobcaw Barony, which comprises 6,475 peninsular hectares (16,000 acres) between the Winyah Bay and the Atlantic Ocean. Once owned by Wall Street financier, Bernard Baruch, and later his daughter, Belle, the property was ultimately left to a trust in 1964, and the Belle W. Baruch Foundation was established to manage it in perpetuity. According to Belle's wishes, the state colleges and universities of South Carolina were granted access to the property to research and conserve its array of natural ecosystems. Under this agreement, BICEFS was established by Clemson in 1968, with the tripartite research mission of forestry, freshwater wildlife science, and beach stabilization. Over the years, BICEFS' work laid the groundwork for the South Carolina Forestry Commission's best management practices for statewide water and soil protection, among other contributions.

Today, BICEFS consists of ten research faculty, two emeritus faculty, one extension specialist, eight lab staff, plus an array of post-docs and grad students. The numbers swell in the summers with the addition of undergraduate interns. The laboratory work ranges from wildlife sampling to soils to hydrology to biogeochemistry, all revolving around the larger topics of climatic and developmental disturbances and their effects on forest and wetland health. This includes the effects of storm surge salinization on tree growth and carbon sequestration. The property is home to wetland stands of bald cypress and water tupelo, plus dense southern pine forest, portions of which are regularly harvested and replanted. This activity helps fund the Baruch Foundation's ongoing management of the property, and also knits the Hobcaw forests together with the larger South Carolina forest economy.

This institutional history and context were first introduced to the students in the form of a *Request for Proposals* (RFP) document prepared in advance by the Studio faculty, with input from BICEFS director Skip Van Bloem. This RFP also included detailed descriptions of existing facilities, their functions, and their limitations. Existing facilities include an administration and classroom building (completed in 2008), a laboratory building (renovated in 2008), and a residential cottage (completed in 2014) for up to ten guests. To address strategic growth objectives, BICEFS is aiming to double its laboratory space, and add to its housing for interns and other short-term occupants. In addition to lacking in physical lab space, the current laboratory building is also inefficient in its layout, does not easily accommodate dirty-work functions, and lacks adequate workspace for graduate students. In light of these challenges, and under the heading of "Research Support", BICEFS sought planning and design for a new laboratory facility to consolidate lab functions and storage, plus associated renovations to the existing building. The new facility would need to be situated to optimize workflows, while also respecting specific physical parameters imposed by the site.

An interdisciplinary design studio was formed to respond to these needs and to help articulate other, subtler opportunities – both for the building and its surrounding site. Compelled by the low embodied energy and carbon sequestration offered by timber systems, and the opportunity to connect to BICEFS' and the Baruch Foundation's own work in forestry, the decision was made to pursue massive timber structural solutions for the new laboratory building. In so doing, special consideration would be given to the following topics:

- State's forest industry & potential economic and environmental impacts of mass timber production
- Proper sizing and orientation of proposed CLT panels and other associated framing
- Proper staging of timber panel construction, and potential benefits of shorter construction schedule
- Proper detailing of mass timber systems
- Embodied energy analysis of mass timber solutions

Funded by Clemson PSA and the Wallace F. Pate Foundation (a BICEFS supporter), the ultimate goal of the Studio was to produce a compelling design proposal (e.g. Fig. 1) that would be used to initiate fundraising and later serve as a reference point when the University engages professional design services.

Figure 1: Rendering of winning laboratory proposal. Source: (Anderson, Chan, and Heezen 2017)

1.3. Design Studio Setting

The organization of the Hobcaw Studio and the structure of its calendar were instrumental to the success of the project. Importantly, the Studio was divided into three working sections and was interdisciplinary in nature. A group of 14 architecture students took on the housing needs. This group consisted of eleven senior-level undergraduates and three graduate students in their penultimate semester. Another group of 13 architecture students worked on the research support designs (9 undergrads, 4 grads). Finally, ten senior-level undergraduates in landscape architecture were tasked with site design, acting as special consultants to their architecture colleagues.

Likewise, the project schedule was divided into three phases. For the research support project and its associated site designs, the first phase consisted of background research on timber products and construction, detailed site analysis, programming, and schematic design. Students of both disciplines worked individually during this phase, resulting in thirteen initial design proposals for the new lab and four sets of conceptual site strategies. Following Phase 1, which lasted four weeks, the four most promising lab proposals were selected for advancement, and design teams of varying size were formed around each of these proposals. Moreover, each design team was paired with a landscape architecture student, whose skillsets and early concepts were most complementary.

Phase 2 (5 weeks) involved close collaboration between the disciplines and ended with integrated proposals for proper siting, grading, foundations, ground water management, and front-of-house versus back-of-house functions and circulation. This phase also delved into the selection and design of the massive timber structural elements. Group presentations onsite at BICEFS concluded Phase 2, and provided ample feedback directly from BICEFS faculty, staff and students. Phase 3 (6 weeks) kept the groups intact while focusing on technical resolution, embodied energy analysis, and preparation for final reviews. Following Phase 3, a winning design proposal was selected as the basis for fundraising and future development.

Throughout the course of the project, Dr. Van Bloem acted as our client representative, taking part in each project review, helping winnow down the initial proposals, and helping select the winning design in the end. Additional guidance in the area of mass timber utilization was provided during a studio visit from Tom Chung of Leers Weinzapfel Associates, lead architect of the Olver Design Building at UMass Amherst – the first CLT academic building in the United States. Among other subjects, Mr. Chung addressed the life-cycle benefits of CLT, its precision, and its ease-of-construction. Falling within Phase 3 of the project, he was also able to offer technical advice on topics ranging from floor overhangs to direct panel-to-column connections.

2.0. PRE-DESIGN

2.1. Analysis of Wood Industry

The semester began with a crash course in wood and timber construction, and its broader implications for the state and regional forest industries. The lab design students were divided up to study the three overarching topics of forestry, forest products, and building with wood. This exercise helped paint a complete picture of wood utilization, from growth and harvest, to milling, to design and implementation. In addition to the economic facts described in Section 1.1, students learned about the end-uses of different wood species, the network of logging and milling operations throughout the state, the specific building products manufactured in the region, and the opportunities and challenges of wood construction, including relevant building codes.

All of this helped to lay a foundation for the Studio's later work with massive timber building systems, including CLT and glulam. Students could recognize the path of the lumber used in those products, and the range of potential impacts that mass timber adoption would make at all levels. Within this framework, students noted the importance of sustainable forestry practices and learned about the tenets of certification programs such as those offered by the Forest Stewardship Council (FSC) and the Sustainable Forest Initiative (SFI). Of these two, SFI is the more prevalent in South Carolina. Clemson's own *Experimental Forest* represents 7,082 hectares (17,500 acres) of the state's 483,257 hectares (1.19 million acres) of SFI-certified forests[4]. The total SFI-certified area represents about 9% of the state's overall forestland, up from 0.8% in 2013. This trend is driven by market demand for certified, sustainable wood products, often within the building industry, and stands to continue if mass timber manufacturing finds a foothold in the state.

It was at this stage that students also began learning about the carbon benefits of building with wood when it is sustainably grown and harvested. They learned about the comparatively low levels of embodied energy in wood building products, made lower by the use of recycled wood biofuels for powering the sawmills. Additionally, they learned that trees sequester carbon[5], and that wood products store this carbon throughout their lifespans. Importantly, trees take in CO_2 at differential rates as they age, with the rate diminishing after the tree reaches maturity (Oliver 2014). Therefore, regular and responsible harvesting and replanting serves to maximize the net levels of carbon sequestered in the system. For this reason, a robust market for wood products, including massive timber, is critical for optimizing the total carbon benefits of our forests.

2.2. Site Analysis and Constraints

The Studio made its first site visit to Hobcaw during the second week of the course, and students presented the background research described above. This served the dual purposes of introducing the wood utilization focus to BICEFS personnel, and gathering their feedback on these topics. Conversely, select BICEFS faculty shared from their own research, giving our students a keener understanding of the diverse set of needs to be addressed in the new and renovated laboratory facilities. This was followed by guided visits to various field research locations around the property, from the estuarial marshes to the cypress swamps to the loblolly pine stands, driving home for the students the integrated nature of this work and its relevance to the systemic effects of climate change. It also provided a sense of the rhythms of fieldwork and the cycles of going out from and returning back to the labs. Tours through the existing labs further illustrated these work flows and the value of good circulation, storage, and support, items lacking in the current BICEFS set-up.

For the sake of operational efficiency, and to minimize disturbance and infrastructure, it was clearly important to locate the new research support facility close to the existing lab and the administration building.

In addition to the lessons described above, students were introduced to three very important and specific constraints associated with this immediate building site. The first constraint related to fire separation. During his own presentation to the Studio, the executive director of the Baruch Foundation described the forest management practices on the property, and the importance of prescribed burns, which serve to control the underbrush and thereby safeguard against both wildfires and threatening insects, such as the Southern pine beetle. Given the periodic need for these burns, a firebreak is required to separate the research campus and its buildings from the forest edge to the south. This translates to a clear space of around 15.24m (50ft).

The second constraint had been described in the earlier RFP document, but was elaborated upon in a presentation from the presiding agent of the Fish and Wildlife Service. The red cockaded woodpecker (RCW) is a protected bird species that nests in the cavities of mature longleaf pines. Federally protected since 1970, its coastal habitat was greatly diminished by Hurricane Hugo in 1989 (Williams 2002). Of the remaining RCW clusters on the Hobcaw property, one is located immediately to the northwest and southwest of the BICEFS research campus. The foraging pattern of these close-by RCWs equates to a routine flight path around the western end of the existing lab facility, thereby restricting any new construction and instead relegating it to the area remaining on the east. Moreover, the breeding season of the RCW will limit onsite construction activities to the months of July through March.

The third constraint was described by the BICEFS director when he pointed out a low area east of the lab that is prone to flooding during major rain events. He was able to indicate the approximate flood level from a recent hurricane, making clear the need to address this topic in the proposed building and site designs to follow. Students noted two wetland areas at the boundaries of the site, one constructed and one natural, and began thinking about opportunities to create a comprehensive water management strategy for the campus.

3.0. DESIGNING SOLUTIONS

3.1. Site and Building Planning

Following the predesign analyses, and in light of the specific constraints described above, the students began planning for the new research support facility, its programming, and its specific location and orientation. The most promising solutions from Phase 1 were advanced by the interdisciplinary teams of Phases 2 and 3. Each of the final proposals incorporated a service road along the southern edge to provide for back-of-house access while doubling as a firebreak. Due to the restrictions imposed by the flight path of the RCWs, each of the proposals also elected to site the new building to the east of the existing lab, meaning that each design had to contend with potential flooding at this location. The approaches on this point differed. One group elected to build on the highest ground, immediately adjacent to the existing lab. This dictated a less-than-ideal building orientation resulting in problematic east and west sun exposures that required deeply louvered facades. Another group proposed more extensive grading to reshape the land and build on the resulting plateau. The remaining two groups elected to bridge the new buildings over the flood plane to varying degrees, while locating at the ground level the utilitarian workspaces, locker rooms, and other such functions that could withstand flooding without damage (e.g. Fig. 2). Noting the need to protect wood construction from moisture cycles, the lower levels in these bridging schemes feature combinations of more durable materials, such as reinforced concrete and Cor-Ten steel. All four of the designs proposed some form of on-site water retention, followed by drainage to the natural wetland to the south.

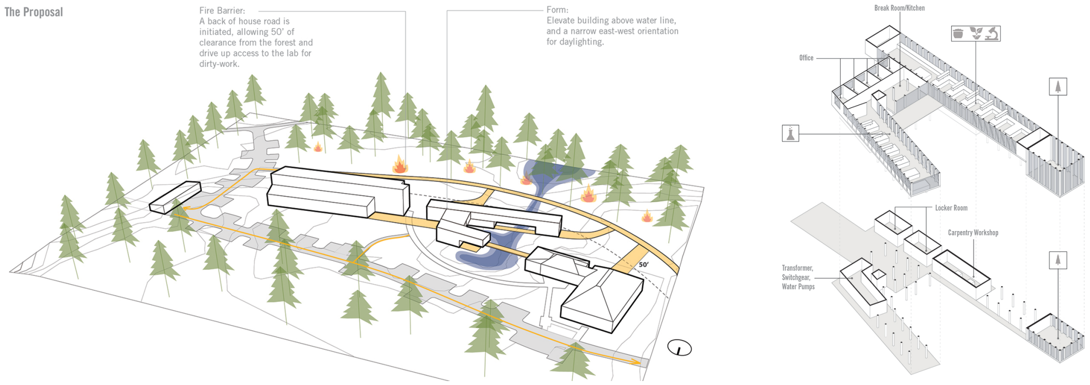

Figure 2: Diagrams of site design strategies and program layout. Source: (Anderson, Chan, and Heezen 2017)

At these early stages, the prospect of mass timber presented two distinct advantages for construction. First, timber offers a very high strength-to-weight ratio, and this lightness supported the notion of structures spanning over the retention area. Additionally, this reduction in weight versus other forms of construction[6], equates to reduced sizing for the building's foundation systems, further minimizing the necessary sitework. This is a common point of emphasis among designers experienced with mass timber projects. The second compelling advantage relates to the constructability of timber panel systems like CLT. The prefabricated nature of these products, paired with easy connections between members, generally equates to accelerated on-site construction schedules. This point is particularly promising for BICEFS, as it must plan around the restrictions imposed by the RCW breeding season. In each of the final design proposals, construction could easily be staged from the south of the site, with efficient panel delivery via the new service road.

3.2. Mass Timber Development

Following the schematic design stages of Phase 1 and early-Phase 2, students progressed into a period of technical development and documentation, including in-depth development of the massive timber building systems. Each of the teams elected to use some combination of CLT panels and glulam framing members. They produced a scaled structural model and accompanying diagrams indicating the placement and relative dimensions of each component in the system. This involved researching span capacities as a function of panel thickness, and also considering the benefits of repeating module sizes, all while making sure that beams and walls were adequately placed to support floor and roof panels. Students also learned that the outer plies of a CLT panel should be oriented to optimize the structural performance in its given role. This meant longitudinally in the direction of span to maximize stiffness of floors and roofs, and vertically for high compression strength in walls. One design team even chose to vary the span direction and sizing of its floor and roof panels in order to most efficiently bridge over the water retention below. In all cases, panel sizes were limited to 3.05m x 18.29m (10ft x 60ft) or less, as this tends to be the upper limit for manufacturers.

From there, students moved into the resolution of the building envelope. Working from case study examples, the design teams interpreted the best strategies for continuous insulating layers and moisture protection. It was at this point that they came to appreciate the additional insulating value of timber itself, which offers an R-value of around 0.55 per cm (1.4 per inch) for softwoods. Each team was required to present detailed wall section drawings articulating the various layers at work in the envelopes. This was also a point that demanded critical analysis of the practical limitations of CLT for this application, namely the durability of exposed floor surfaces. In response, concrete skim coats were specified for laboratory floor surfaces, and recommended separation distances from ground level were observed for any first-story timber components.

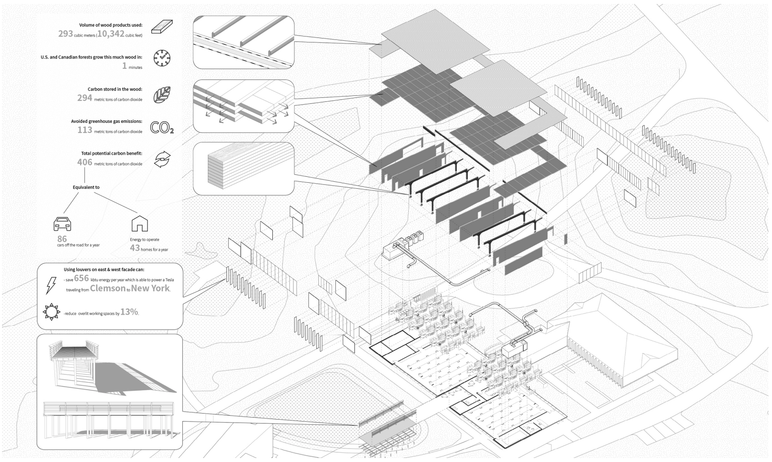

Figure 3: Axonometric diagram articulating timber building system. Source: (Xia, Day, Liang, and Schoonmaker 2017)

3.3. Life Cycle Energy

Building upon the carbon benefits of wood suggested by the background research of Phase 1, students were required in the later stages to estimate the embodied energy of the timber structural systems employed in their design solutions. This served to further cement for them the importance of a full life-cycle understanding of energy, from harvest and manufacturing to transportation and construction – each coming before the operational energy of the completed building to which they were more accustomed. Digital modeling provided an important foundation for these calculations, in that accurate models (e.g. Fig. 3) enabled the quick reporting of member volumes. Three of the four design teams were well-versed enough to use BIM software (in this case, Revit by Autodesk), and could therefore take things a step further through material and assembly definitions. These definitions were essential as the Studio forayed into the use of Tally, a professional life-cycle assessment tool that runs as a plug-in for Revit. This tool was effective for illustrating the myriad factors that go into predictive LCA analyses, and students were asked to make certain baseline assumptions for transportation distances and other inputs. Ultimately, however, Tally required a level of technical understanding of building assemblies that was deeper than what the Studio, and in particular the undergraduates, brought to the table. It was the metaphorical scalpel, when we needed more of a blunt instrument at this stage to study the timber components in isolation. This, when paired with the fast pace of the project and the timeline of deliverables, contributed to a decision to shift directions.

The Studio turned to a simple carbon calculator[7] devised by *WoodWorks*, an education and technical support organization funded by the softwood lumber industry and the U.S. Forest Service. This calculator requires volumetric inputs for lumber and massive timber elements, and area inputs for sheathing. It also allows for the designation of wood species. Outputs include the total mass of CO_2 sequestered, and an estimation of the total greenhouse gas emissions avoided by using timber rather than other conventional structural materials. This GHG estimation utilizes a displacement factor based on building construction type and an array of LCA case studies across materials. It also assumes an end-of-life scenario in which any timber elements would be diverted from landfills and either recycled or used for energy recovery. Table 1 below shows the carbon impact results from the timber structural components of each of the four laboratory design proposals. Wood sheathing, decking, and façade treatments were omitted from these calculations below, though they were included at other points along the way by certain teams.

Table 1: Carbon footprint data for timber superstructures. Source: (Author 2018)

Project Team (conditioned area, m^2)	*Structural Timber Volume, m^3 (ft^3)*	*CO_2 Sequestered, metric tons*	*Total Avoided Greenhouse Gas Emissions[4], metric tons*
Anderson, et al (661)	292 (10,327)	295	114
Rowell, et al (1,372)	450 (15,893)	454	176
Xia, et al (936)	287 (10,139)	290	112
White, et al (1,408)	413 (14,594)	417	161

4.0. FOLLOW-UP RESEARCH

The work described in this paper relative to carbon impact analysis is clearly a rudimentary first step. Having recently completed the central design deliverables for BICEFS, the project team is now poised to delve into a more detailed analysis of the embodied energies and other LCA impacts posed by the selected laboratory proposal. We will turn again to Tally as a tool for this exercise. In so doing, one goal is to redesign the laboratory structure in steel and in concrete and run comparisons against the data generated for massive timber. This will also allow cross-comparison with the initial GHG estimations rendered by the WoodWorks calculator. Moreover, this work would set the table for broader questions, such as: what is the total potential GHG impact (including sequestered carbon) if Clemson University adopted wood and timber systems for all new construction proposed in its master plan? Can the expanding campus begin to act as a carbon sink?

Another area of follow-up research lies further in the future. If BICEFS completes a new research support facility using CLT, then it will be another key structure in the growing list of reference points for mass timber construction. To maximize its impact, it is important to thoroughly document its costs and any lessons from construction. It will also be valuable to monitor the structural and envelope performance over time. Following initial discussions on the matter, BICEFS indicated a keen interest in pursuing wireless sensing to measure moisture, temperature gradients, and structural vibrations. Such monitoring will shed light on the long-term behaviors of mass timber structures, an area for which there is currently little data in North America.

CONCLUSION

In conclusion, the 2017 Hobcaw Studio described in this paper proved to be successful in at least three significant ways, with each having connections to the emphasis on massive timber. First, the interdisciplinary collaboration between students of architecture and students of landscape architecture was critical for developing comprehensive and cohesive design solutions for the sensitive setting. In this regard, the potential advantages of CLT for both weight and construction schedule were understood and appreciated by all involved. The focus on timber also served to effectively attune the students of both disciplines to the larger forest industry and its connections to the ongoing research activities of BICEFS, our “client.”

Second, the project provided students with a new knowledge of embodied energy. The graduate students in the course were already versed in consumptive energy modeling, and were even called upon to use those skills to study the effects of various shading strategies. However, embodied energy and its place in life cycle assessment was largely uncharted territory for the class. The use of quantitative tools, though encumbered by the limitations noted in Section 3.3, effectively grounded and made tangible this aspect of the work.

Finally, the Studio served as a model for combining and balancing a funded service learning project and its associated demands with a material-focused research agenda. This, of course, required front-end support from BICEFS for the topic of mass timber and an acknowledgment of the potential synergies in its use for the new facility. The benefits of service learning scenarios are well understood to include the experiences of working directly with specific clients, their real needs, and their constraints. This was certainly the case with the Hobcaw Studio, and the embedded competition format further drove solutions that were both innovative and responsive to BICEFS' requirements and concerns. Likewise, the depth of emphasis on massive timber systems equally led to a clarity and focus in the work of the Studio. The resulting design products from this unique arrangement were mutually beneficial to BICEFS, as solutions to their institutional needs, and to the course faculty, for whom the work serves as a platform for further research – both in the area of forest industry impacts as well as the deeper material and performance analyses described above.

ACKNOWLEDGEMENTS

Thank you to Paul Russell and Dan Harding, my co-instructors. Thank you to Chelsea Anderson, Allison Chan, and Chris Sandkuhler, our student assistants, and to Dr. Skip Van Bloem and his BICEFS faculty and staff for their support throughout the project. Thank you to the Wallace F. Pate foundation for its support.

REFERENCES

Anderson, Chelsea, Allison Chan, and Emily Heezen. 2017. *Over the Water*. Clemson, South Carolina: Clemson University School of Architecture.

Douglas, Brad, and Erol Karacabeyli, editors, 2013. *CLT Handbook, U.S. Edition*. Pointe-Claire, Quebec: FP Innovations.

International Code Council. 2014. *2015 International Building Code*. Birmingham, AL: ICC.

"Economic Contribution Analysis of SC's Forestry Sector, 2017," accessed January 31, 2018, http://www.state.sc.us/forest/economicimpactstudy2017.pdf

"Forests of SC, 2016," accessed January 31, 2018, https://www.state.sc.us/forest/scfia16.pdf

Oliver, Chadwick, Nedal Nassar, Bruce Lippke, and James McCarter, 2014. *Carbon, Fossil Fuel, and Biodiversity Mitigation with Wood and Forests. Journal of Sustainable Forestry*. London: Taylor & Francis.

Williams, Thomas and Donald Lipscomb, 2002. *Natural Recovery of Red-Cockaded Woodpecker Cavity Trees After Hurricane Hugo*. Southern Journal of Applied Forestry. Washington, DC: Society of American Foresters.

Xia, Yin, Nicholas Day, Chen Liang, and Megan Schoonmaker. 2017. *Connecting Nodes*. Clemson, SC: Clemson University School of Architecture

ENDNOTES

[1] Cross-Laminated Timber is a panelized timber building product, in which the laminated layers of lumber are laid in alternating grain directions to one another. This enhances dimensional stability of the panels.

[2] The John W. Olver Design Building (2017) at UMass Amherst was originally designed as a steel building. According to project architect, Tom Chung, the structure was modified to mass timber during the late stages of the design development phase. This decision was driven by the research interests of faculty within the Building and Construction Technology department, one of the multiple disciplines housed in the new facility.

[3] IB X-LAM USA, a division of International Beam, will produce CLT out of its new plant in Dothan, Alabama.

[4] Notably, the forests on the Hobcaw property are certified within the American Treefarm certification program, which is recognized for SFI chain-of-custody.

[5] Carbon accounts for approximately 50% of the dry weight of softwood trees.

[6] For reference, Southern Pine has a density of approximately 640 kg/m^3 (40pcf), whereas concrete density, is approximately 2,403 kg/m^3 (150pcf). This is a considerable difference when comparing floor systems.

[7] The WoodWorks Carbon Calculator can be found at http://cc.woodworks.org/calculator.php?country=us. A detailed description of the background assumptions and displacement factors is included at http://www.cc.woodworks.org/WW_references_notes.pdf.